SID '94 p 245
Eblen, Gunning, I
Hale, Yeh, Kho

2

17.4: Birefringent Compensators for Normally White TN-LCDs

J. P. Eblen, Jr., W. J. Gunning, J. Beedy, D. Taber, L. Hale, P. Yeh, M. Khoshnevisan
Rockwell International Science Center, Thousand Oaks, CA

ABSTRACT

A novel, producible compensator for twisted nematic liquid crystal displays operated in the normally white mode has been developed for avionics applications. The 20:1 isocontrast region has been extended to ± 50° in displays incorporating the compensator, an improvement of 10° or more relative to uncompensated displays. The compensator design includes integrated antireflection coatings to reduce glare, a critical requirement for avionics. The compensator has been integrated into production avionics displays.

INTRODUCTION

Background

There is an emerging demand for flat panel displays (FPD's) for avionics applications. Of the various FPD products currently available, only active matrix twisted nematic liquid crystal displays (TN-LCD's) offer sufficient performance to simultaneously address the avionics requirements of luminance, resolution, color capability, and frame rate.

The asymmetric viewing angle characteristics and narrow viewing angle region of TN-LCD's are well-known[1]. For TN-LCD's operated in the normally white (NW) mode, or the mode in which the TN-LCD is transmissive in the undriven state, the horizontal viewing region is typically restricted to a narrow range centered about 0°. This is a critical issue for avionics displays, where cross-cockpit viewing is often required.

Loss of contrast at high viewing angles is the result of light leakage in the dark state, which is the driven state in a NW display. The liquid crystal layer in this state may be characterized as having positive birefringence with the optic axis nearly parallel to the applied electric field. A device with the opposite symmetry, also known as a negative c-plate, is known to compensate this state[2]. This symmetry has been previously implemented by the ultra-supertwist liquid crystal compensator, a highly twisted nematic liquid crystal device[3]. Certain types of compensation films have also been shown to exhibit this symmetry[4]. At the present time, cost is an issue for large area liquid crystal devices such as the ultra-supertwist structure. Furthermore, uniformity over a large area must be addressed for any compensation scheme.

Objectives

The objectives of this work are to demonstrate producible avionics-grade compensators having negative c-plate symmetry, and to demonstrate improved contrast performance in TN-LCD's using these compensators. A compensator which is a producible, high optical quality device with low glare and insertion loss is described.

NEGATIVE C-PLATE COMPENSATOR DESIGN

Symmetry Considerations

Because the contrast degradation at high viewing angles is the result of light leakage in the dark state, a compensator which will compensate the dark state without significantly altering the white state is needed. Symmetry considerations led to the following device configuration. Consider a 90° twisted nematic display in the black state. This quasihomeotropic state can be approximated as a positive c-plate retarder (that is, a positive birefringent element with its optic, or c, axis normal to the plane of the device) sandwiched between crossed positive a-plate retarders (that is, positive birefringent materials with their optic axes in the planes of the devices). For the purpose of discussion, this state is approximated as homeotropic, or a positive c-plate. Thus, a birefringent element with the opposite symmetry, or negative c-plate, can be used to cancel the dominant optical phase shifts due to the birefringence of the liquid crystal by introducing an optical phase shift with the same angular dependence as the positive element, but opposite in sign.

The same symmetry conditions predict that a negative c-plate has little or no effect on the luminance of the white state.

One important consideration is that high drive voltages produce driven states that are closer approximations to homeotropic than low drive voltages. Thus the compensator is expected to be more effective when used in combination with high drive voltages.

Additionally, the drive voltage must be considered when designing compensators for specific applications.

ISSN0097-0966X/94/2501-0245-$1.00 + .00 © 1994 SID

Design

In this work the phenomenon of form birefringence[5] is utilized to engineer a material with the appropriate negative birefringence. This material is fabricated by physical vapor deposition of a stack of alternating thin layers of optical materials having different refractive indices[6].

The compensator is fabricated by vacuum deposition of alternating thin layers (200 Å thick) of silicon dioxide and titanium dioxide. The physical vapor deposition process is well-known to produce uniform optical quality devices[7]. In particular, uniformity can be achieved over large areas.

Simple theoretical arguments predict the behavior for the ordinary refractive index, n_o, and extraordinary refractive index, n_e, of a film composed of alternating layers of two materials of equal thickness as follows[5]:

$$n_o^2 = (n_1^2 + n_2^2)/2$$
$$1/n_e^2 = (1/n_1^2 + 1/n_2^2)/2$$

For the case of silicon dioxide (n_1=1.53, a typical value for thin films) and titanium dioxide (n_2=2.13, a typical value for thin films) layers, the predicted values of n_o and n_e are 1.85 and 1.75, respectively. The total retardation value of the film is given by the product of the birefringence, $\Delta n = n_e - n_o$, and the film thickness, d.

The birefringence for a stack of alternating layers of equal thickness is independent of layer thickness according to this simple model. For display compensators, the layers must be thin compared to visible wavelengths so that no reflection bands are observed. The average layer thickness of 200 Å satisfies this condition (Fig. 1).

In addition, this structure is amenable to incorporation of antireflection layers to reduce specular reflectance, a critical requirement for sunlight readability in avionics applications. These antireflection layers are designed to produce low specular reflectance when interfaced to both glass and the lamination materials used in fabricating the displays. Specular reflectance values of 0.1% to 0.2% are routinely achieved for these compensators, resulting in minimized glare and insertion loss in display products.

The compensator design comprises a central region with alternating 200 Å layers of SiO_2 and TiO_2, sandwiched between identical 5-layer antireflection coatings, which are also fabricated from SiO_2 and TiO_2 (Fig. 2).

Ellipsometric measurements[8] confirm that films fabricated according to this design behave like negative uniaxial crystals with n_o = 1.85 and n_e = 1.75 with optic axes normal to the plane of the films (Fig. 3).

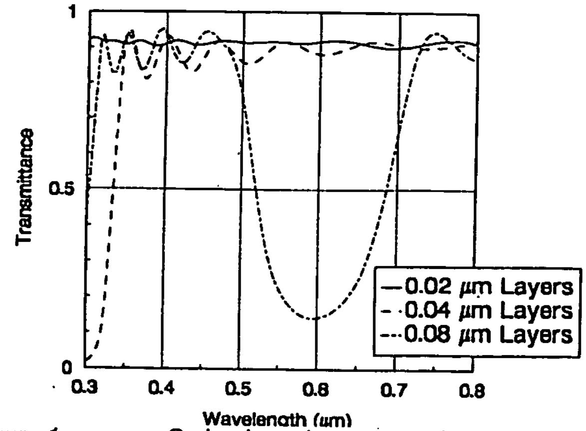

Figure 1. Calculated transmittance of compensators with varying layer thicknesses, showing elimination of interference effects for 0.02μm layers.

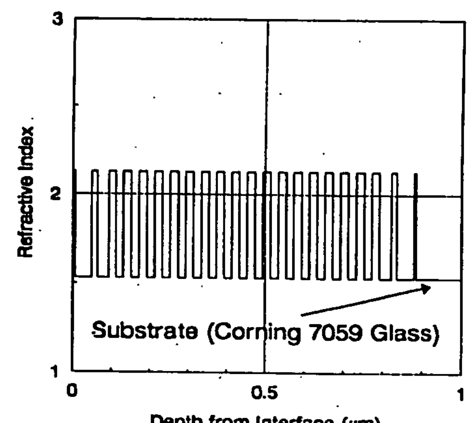

Fig. 2. Negative c-plate compensator with antireflection coatings (ARC's). Compensator consists of a 33 layer structure with alternating layers of TiO_2 and SiO_2 and five layer ARC's.

Performance Predictions

Theoretical predictions of the display contrast improvement to be expected have been performed based on the 2x2 extended Jones matrix method[9]. A significant improvement in horizontal viewing angle was predicted, especially with the application of higher drive voltage. It was predicted that the horizontal viewing region (defined by the 20:1 isocontrast contour when the display is driven at 9.7 volts) is enlarged from less than ±40° in the horizontal viewing direction in the uncompensated case to ±50° for the compensated case.

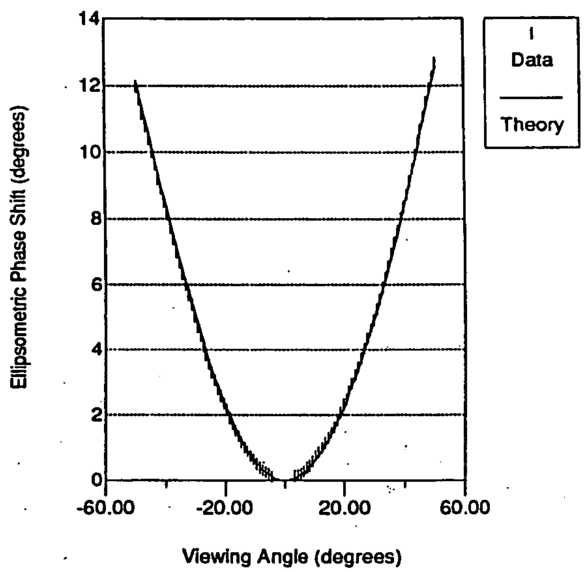

Figure 3. Ellipsometric phase shift, showing that the negative c-plate compensator behaves like a uniaxial crystal with its optic axis perpendicular to the plane of the device.

Display Measurements

Experimental data on liquid crystal displays verified the theoretical predictions (Fig. 4 and 5). Full-color (luminance) contrast measurements were performed on a display with a cell gap, d, of 5.9μm and liquid crystal birefringence, Δn, of 0.083. It was experimentally determined that the optimum compensation of the display was provided by a negative c-plate with Δnd = 265 nm. Uncompensated displays showed degraded contrast at high viewing

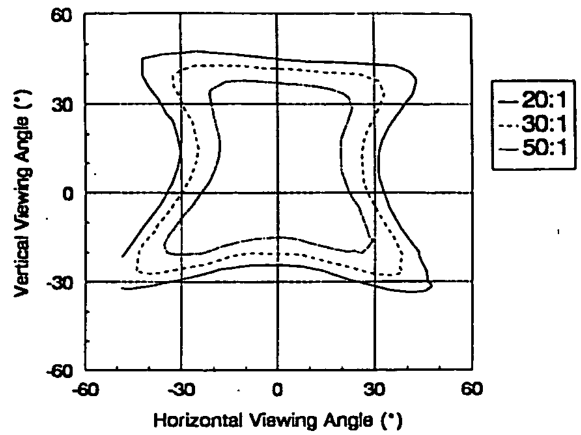

Figure 4. Uncompensated normally white liquid crystal display, showing compressed horizontal viewing angle.

angles (Fig. 6). Contrast Excellent, colorless black states were observed on compensated displays (Fig. 7). The region of high contrast was significantly expanded in the horizontal direction. The 20:1 isocontrast contour has been extended to ±50° or greater, an improvement of 10 degrees or more degrees, relative to the uncompensated case, in both the left and right viewing hemisphere. The horizontal performance is sufficiently enhanced to facilitate cross-cockpit viewing.

Note that the vertical viewing region has been decreased by the addition of the compensator. The remaining viewing range is still well within the current requirements for avionics displays, where +30° in the vertical direction and -10° in the vertical direction are normally sufficient.

IMPACT

The display compensator described in this paper has been integrated into a variety of avionics display products. The negative c-plate compensator produces considerable performance improvements in LCD-based avionics displays with only modest increases in cost. Because the compensator is a component which is assembled into a display unit rather than integral to the liquid crystal panel, no yield factor is introduced into the production of the LCD panels, the primary cost driver.

REFERENCES

1. A. Lien, H. Takano, S. Suzuki, and H. Uchida, "The Symmetry Property of a 90° Nematic

Liquid Crystal Cell," Mol. Cryst. Liq. Cryst. 198, 37 (1991).

2. H.L. Ong, "New Normally White Negative Birefringence Film Compensated Twisted Nematic LCD's with Largest Viewing Angle Performance," Japan Display '92 Digest, p. 247 (1992).
3. H. Hatoh, M. Ishikawa, Y. Hisatake, J. Hirata, and T. Yamamoto, "Viewing-Angle Magnification in a TN-LCD with an Ultra-Supertwisted LC Compensator," SID '92 Digest of Technical Papers, p. 401 (1992).
4. J. F. Clerc, "Vertically Aligned Liquid-Crystal Displays," SID '91 Digest, p. 758 (1991).
5. Pochi Yeh, *Optical Waves in Layered Media* (John Wiley & Sons, New York, 1988) pp. 135-138.
6. U.S. Patent No. 5,196,953. P. Yeh, W.J. Gunning, J.P. Eblen, Jr., and M. Khoshnevisan, "Compensator for liquid crystal displays having two types of layers with different refractive indices alternating."
7. H.A. Macleod, *Thin Film Optical Filters, 2nd Ed.* (Macmillan, New York, 1986) pp.357 -445.
8. L.G. Hale, D. Taber, E. Schonning, D. Rizzi, W. Gunning, and J. Eblen, "Ellipsometric Measurements Applied to Liquid Crystal Display Technology," submitted for presentation to the 1994 annual meeting of the Society of Photo-optical and Instrumentation Engineers (San Diego '94)
9. A. Lien, "Extended Jones matrix representation for the twisted nematic liquid-crystal display at oblique incidence," Appl. Phys. Lett. 57, 2767 (1990).

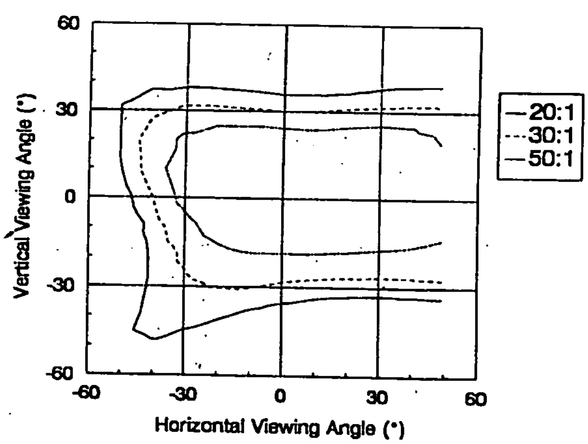

Figure 5. Normally white liquid crystal display compensated with the negative c-plate compensator, showing expanded contrast in the horizontal direction.

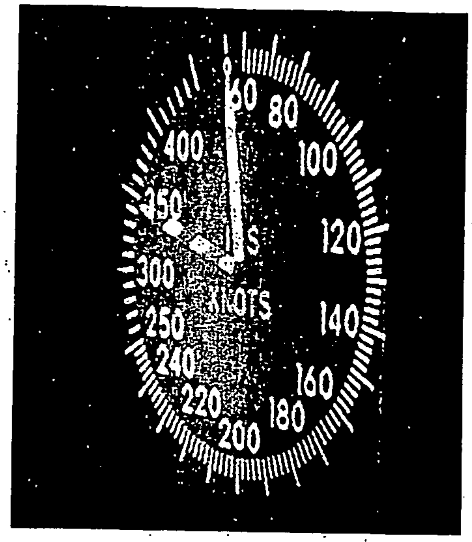

Figure 6. Photograph of an uncompensated display, showing reduced contrast at high viewing angles.

This figure is reproduced in color on page 991.

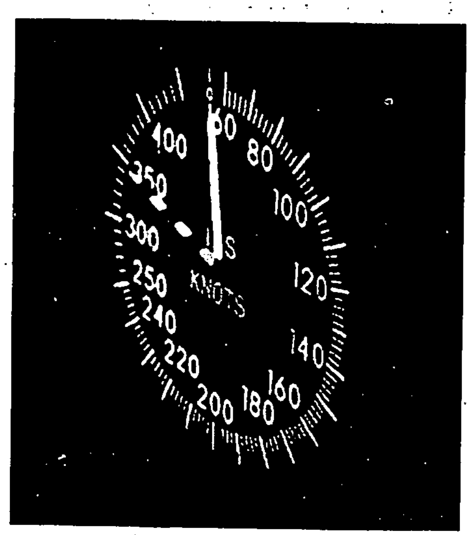

Figure 7. Photograph of a compensated display, showing enhanced contrast at high viewing angles.

This figure is reproduced in color on page 991.